

Basic technique and interpretation

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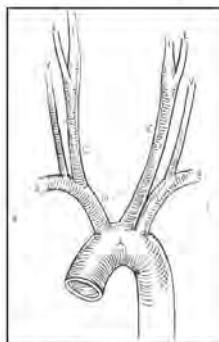
Doppler US of carotid arteries

- ❶ Anatomy of carotid arteries
- ❷ Normal Doppler US of carotid arteries
- ❸ Causes of carotid artery disease
- ❹ Effect of extra-carotid diseases

PART I

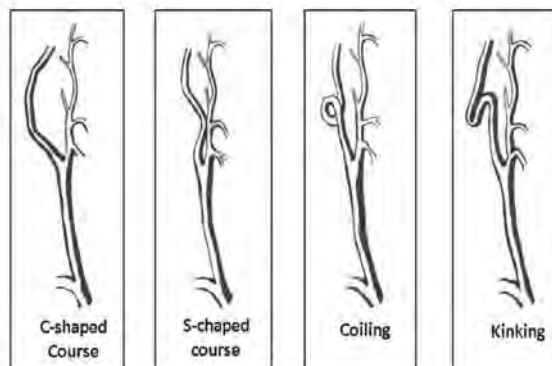
- ☐ Anatomy of carotid arteries
- ☐ Normal Doppler US of carotid arteries
- ☐ Causes of carotid artery disease
 - Common Carotid Artery
 - Internal Carotid Artery
 - External carotid Artery

Extra cranial cerebral arteries

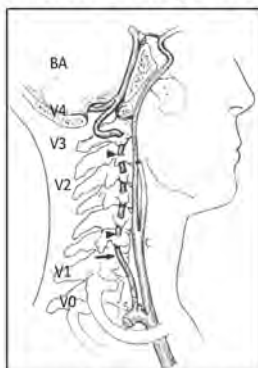


All arteries that carry blood from heart up to base of skull
Right & left sides of extra cranial circulation not symmetrical

Variants resulting from elongation of ICA



Vertebral artery course



VAs asymmetric in 75 % – Left dominant in 80 %
 Posteriorly directed loop when exists C1 transverse process
 2 VAs units to form basilar artery: collateralization

Doppler US of carotid arteries

- ① Anatomy of carotid arteries
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- ④ Effect of extra-carotid diseases

All carotid artery examinations should be performed with:

- Gray-scale US
- Color Doppler
- Power Doppler
- Spectral Doppler

Integrate gray scale, color flow, & spectral findings

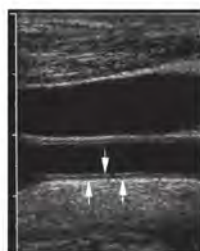
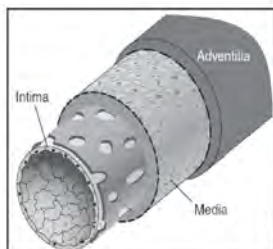
Tahmasebpour HR et al. RadioGraphics 2005 ; 25 : 1561 – 1575.

Doppler ultrasound of carotid arteries / Tips

- Begin each scan on same side, usually the right
- Avoid excess pressure on carotid bifurcation to avoid
 - Stimulate carotid sinus **Bradycardia**
 - Syncope**
 - Ventricular asystole**
 - Compress arteries to cause spurious **high velocities**

Intima-Media complex

Normal value ≤ 0.8 -9mm



Wall of CCA, bulb, or ICA
 Best measured on far wall
 Only intima & media included

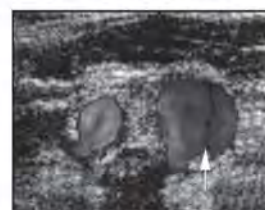
Normal carotid bifurcation

Black & white US



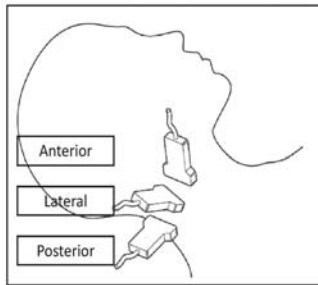
ICA Larger & lateral
 ECA Smaller & internal

Color Doppler ultrasound



Normal flow separation

Longitudinal scan to visualize carotid arteries

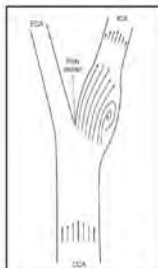


Carotid bifurcation



Longitudinal B-mode image of carotid bifurcation
ICA & ECA seen in same plane

Normal flow reversal zone in ICA



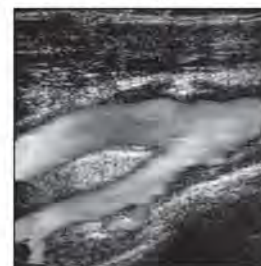
Velocities highest near flow divider
Flow reversal on opposite side
to flow divider



Flow reversal zone
Opposite to origin of ECA

Internal & external carotid artery

Power Doppler US

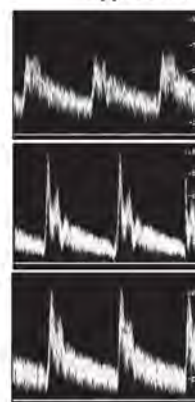


2 small branches originating from ECA

Standard Doppler spectral examination

Traces obtained from	
• CCA	Proximal – Distal
• Carotid Bulb	
• ICA	Proximal – Middle – Distal
• ECA	Proximal
• Vertebral Artery V0 – V1 – V2	
• SCA	

Typical normal Doppler spectra



Internal carotid artery

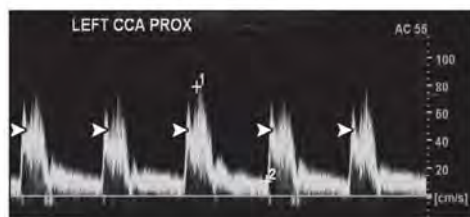
PSV: 45 – 125 cm/sec
Difference between 2 sides < 15 cm/sec

External carotid artery

Common carotid artery

Dicrotic notch

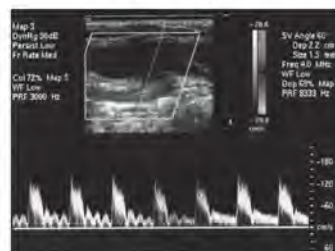
Normal feature



Closure of aortic valve with temporary cessation of forward flow
Resumption of forward flow by elastic rebound of aortic wall

Temporal tapping of ECA

"Saw-tooth" appearance



Small regular deflections (TT)

Frequency corresponds to rate of temporal tapping

Deflections best seen during diastole

Differentiation between ICA & ECA

Features	ICA	ECA
① Size	Usually larger	Usually smaller
② Branches	Rarely	Yes
③ Orientation	Posterior	Anterior
④ Pulsed Doppler	Low resistance	High resistance
⑤ Temporal tap	Usually negative	Usually positive

Protocol for VA examination

Longitudinal VA between transverse processes

- Direction of flow
- Waveform configuration
- Measure PSV

Caudad survey

- Follow artery caudad to its origin

Cephalad survey

- Follow artery cephalad above transverse processes

Ultrasound of normal vertebral vessels

Vertebral artery

Cephalad flow throughout cardiac cycle
Low resistance flow pattern
VA origin regularly seen by experienced sonographers
Size: variable & asymmetric – Mean diameter 4 mm
PSV: 20 – 40 cm/sec – <10 cm/sec potentially abnormal

Vertebral vein

May occasionally be seen adjacent to VA
Flow caudad & nonpulsatile

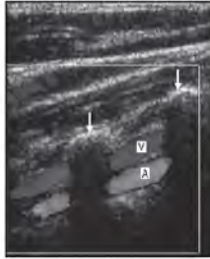
Normal vertebral artery origin

V0

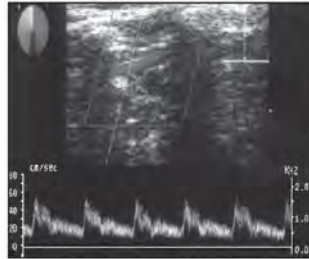


Normal vertebral artery & vein V2

Color Doppler



Pulsed Doppler



Vertebral artery & vein seen between vertebral processes of spine

Subclavian artery

Color Doppler US



Mirror image below pleura

Pulsed Doppler US



Normal triphasic waveform

Doppler US of carotid arteries

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Causes of carotid artery diseases

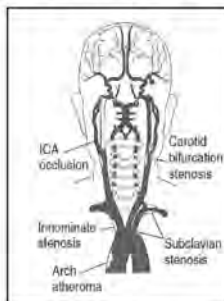
Arteriosclerotic disease

Most common cause

Non-arteriosclerotic diseases

- Fibro muscular dysplasia
- Dissection
- Vasospasm
- Aneurysm & pseudo aneurysm
- Arterio-venous fistula
- Arteritis: Takayasu – Horton
- Carotid body tumor
- Idiopathic carotidynia

Common sites for extracranial arterial disease



Most common site at carotid bifurcation
with plaque extending into ICA

Plaque characterization

① Echogenicity

- | | |
|------------------|----------------------------------|
| Low | Lipid – Flow void |
| Moderate | Collagen – Easy to see |
| High with shadow | Calcification – Focal or diffuse |

② Heterogenous plaque

- Calcification: no correlation with neurologic symptoms
- Focal hypoechoic zones: Hemorrhage – Necrosis – Lipid

③ Plaque surface features

- Common sources of cerebral emboli: TIA – Stroke
- Poor US results for ulcer detection

Appearance of atheromatous plaques

Homogeneous echolucent



Heterogeneous plaque



Homogeneous echogenic



'Cauliflower' calcification



Calcified plaque



Calcific plaque with shadow obscuring portion of the bulb

Interrogate artery beyond plaque
Shadowing segment < 1 cm
No turbulent flow: insignificant stenosis
Damped or turbulent flow: tight stenosis

Shadowing segment > 2 cm
Degree of stenosis indeterminate
Other modalities recommended

Intraplaque hemorrhage



Sources of error in ulcer diagnosis

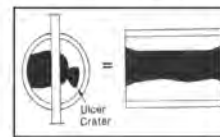
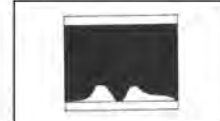
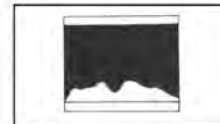


Image plan does not include the ulcer



Adjacent plaque simulate ulceration



Plaque surface irregular but not ulcerated

Large plaque ulcer

Color Doppler

Pseudo-dissection

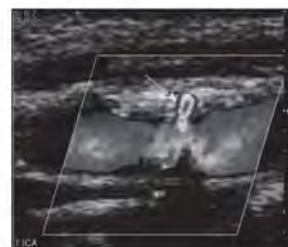


Power Doppler

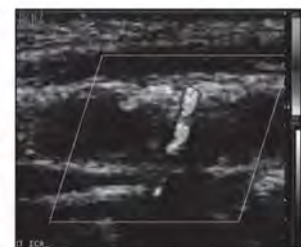
"eddy flow"



Ulcerated plaque or twinkle artifact



Hard plaque in proximal ICA
Questionable flow at plaque surface



Scale 86 cm/sec, color in diastole
Color flow disappeared
Color artifact continues to twinkle

Estimation of carotid stenosis

Diameter reduction



Surface reduction



Relationship between diameter reduction & cross-sectional area reduction

Diameter reduction (%)	Cross-sectional area reduction (%)
30	50
50	75
70	90

Cardinal Doppler parameter to grade stenosis

Peak Systolic Velocity (PSV)

Best documented Doppler parameter for carotid stenosis

End Diastolic Velocity (EDV)

Quite valuable for detecting high-grade carotid stenosis

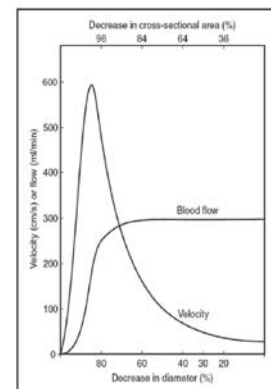
PSV ratio

Avoid errors of collateralization

Avoid errors of physiological factors:

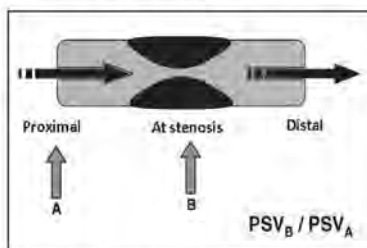
BP – Pulse rate – Cardiac output – Peripheral resistance

Relationship of flow, velocity & lumen size



Spencer MP & Reid JM. Stroke 1979 ; 10 : 326 – 330.

Grading stenosis – PSV ratio



Proximal: 2 cm proximal to carotid bulb

At stenosis: same Doppler angle if possible

Normal value < 2.0

Carotid Artery Stenosis: Gray-Scale and Doppler US Diagnosis – Society of Radiologists in Ultrasound Consensus Conference

17 authors:
1 Moderator
16 panelists

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San Francisco, Calif
October 22–23, 2002

ICA stenosis on angiogram

NASCET ¹ (1991 – 1998)
North American Symptomatic Carotid Endarterectomy Trial
 $(B - A / B) \times 100$

ECST ² (1998)
European Carotid Surgery Trial
 $(C - A / C) \times 100$

¹ NASCET. N Engl J Med 1991 ; 325 : 445 – 453.



ICA stenosis on angiogram

Diameter reduction

* NASCET (B – A / B) x 100	** ECST (C – A / C) x 100
30%	65%
40%	70%
50%	75%
60%	80%
70%	85%
80%	91%
90%	97%

* NASCET: North American Symptomatic Carotid Endarterectomy Trial

** ECST: European Carotid Surgery Trial



Degree of ICA Stenosis in Doppler US*

Consensus Criteria – NASCET criteria

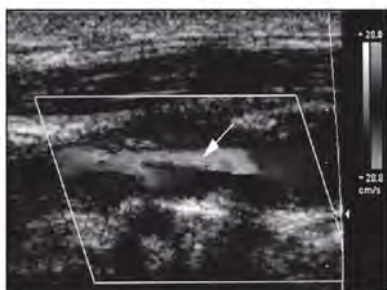
ICA stenosis (%)	ICA PSV cm/sec	ICA EDV cm/sec	PSV ratio ICA/CCA
Normal	< 125	< 40	< 2.0
< 50%	< 125	< 40	< 2.0
50 – 69%	125 – 230	40 – 100	2.0 – 4.0
> 70%	> 230	> 100	> 4.0
Near occlusion	variable	variable	variable
Total occlusion	undetectable	undetectable	not applicable

Degree of ICA Stenosis in Doppler US*

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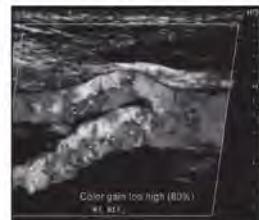
Aliasing or high velocity jet



Area of highest velocity in area of stenosis

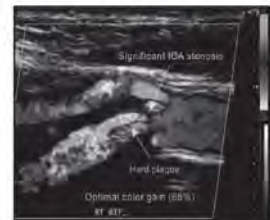
Adjustment of color gain

Color gain at 80%



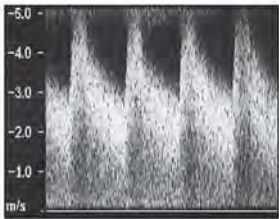
Marked turbulence of ICA & ECA
No luminal narrowing

Color gain at 66%



Anatomy of bifurcation
demonstrated more accurately

ICA stenosis



PSV 500 cm/sec
EDV 300 cm/sec
Spectral broadening
80% diameter stenosis

Post stenotic zone/ Immediately after stenosis

Spectral broadening

- Cannot be precisely quantified (evaluated visually)
- Fill-in of spectral window** > 50% diameter reduction
- Severely disturbed flow** > 70% diameter reduction
 - High amplitude & low frequency Doppler signal
 - Flow reversal
 - Poor definition of spectral border
- May be **only sign of carotid stenosis** in calcified plaque

Spectral broadening Immediately after stenosis



High amplitude & low frequency Doppler signal
Poor definition of spectral border
Flow reversal
↓
Severe spectral broadening: > 70% diameter reduction

Pseudo-spectral broadening

- High gain setting
- Vessel wall motion
- Tortuous vessels
- Site of branching
- Abrupt change in vessel diameter
- ↑ velocity: athlete - high cardiac output - AVF¹ - AVM²
- Aneurysm, dissection, & FMD³

¹AVF: Arterio-Venous Fistula

²AVM: Arterio-Venous Malformation

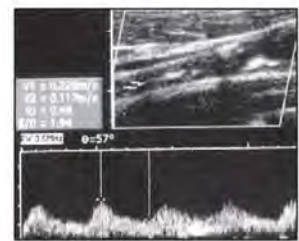
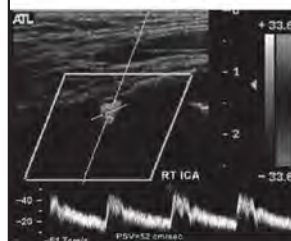
³FMD: Fibro-Muscular Dysplasia

Post stenotic zone / Distal to site of stenosis



Tardus-parvus waveform

High grade "string sign" stenosis



Tardus Parvus waveform

Tardus: Long rise time

Parvus: Low PSV

Sonographic features of severe ICA stenosis

- ❶ Significant visible plaque ($\geq 70\%$ diameter reduction)
- ❷ PSV > 230 cm/sec
- ❸ EDV > 100 cm/sec
- ❹ ICA/CCA PSV ratio ≥ 4.0
- ❺ Spectral broadening
- ❻ Color aliasing despite high velocity scale (100 cm/sec)
- ❼ Color bruit artifact in surrounding tissue of stenosis
- ❽ High-pitched sound at pulsed Doppler

Tight stenosis or occlusion?



- Difficult to distinguish tight stenosis from occlusion
- **Completely occluded ICA**
Will not release emboli
Not corrected by surgery
- **Very severe stenosis**
Potential source for emboli or acute thrombosis
May require urgent surgery

Optimization of low flow velocities

- Decreased color velocity scale
- Increase color, power & pulsed Doppler gain
- Decreased wall filter
- Focal zone at level of diseased segment
- Doppler angle as low as possible (60° or less)
- Increased persistence
- Increase sample volume gate

Subtotal occlusion of ICA "string sign" or "trickle flow"



Narrow channel of low-velocity in subtotal ICA occlusion
Low PRF & low filter required to detect low-velocity flow

Causes of image/Doppler mismatch

- Cardiac arrhythmia
- Severe aortic stenosis
- Hypotension or hypertension
- Tortuous vessels
- Hypoechoic, anechoic or calcified plaques
- Long segment high grade stenosis
- Pre-occlusive lesion
- Tandem lesion
- Contra-lateral carotid stenosis
- Carotid dissection

Short & long stenosis of ICA

Short stenosis (frequent)



Can produce very high PSV
(> 500 cm/s)

Long stenosis (rare)



PSV lower than expected
EDV maintained at high level

Long stenosis of ICA



RICA:	PSV	183 cm/sec
	EDV	105 cm/sec
CCA:	PSV	76 cm/sec
PSV ratio:		2.4
		Inconsistent data

Long stenosis of ICA > 70%

Zwiebel WJ et al. Ultrasound Quarterly 2005 ; 21 : 113 – 122.

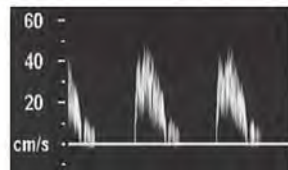
Occlusion of ICA

- **Absence of flow** by color, power & pulsed Doppler
- **“Internalization”** of ipsilateral ECA waveform
- **Reversed flow** in ICA or CCA proximal to occlusion
- Thrombus or plaque completely fills lumen of ICA
- Externalization of ipsilateral CCA or proximal ICA
- Higher velocities in contralateral CCA vs. ipsilateral CCA

Occlusion of ICA



Retrograde flow in stump of ICA
Absence of flow in ICA beyond

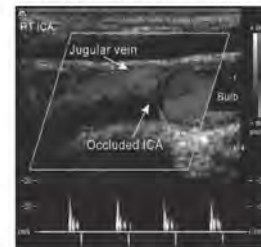


Doppler spectrum from CCA
Externalization of CCA

Occlusion of ICA

“to-and-fro” flow or thud flow

Pulsed Doppler of CCA



Damped systolic flow
Reversed flow in early diastole

Tahmasebpour HR et al. RadioGraphics 2005 ; 25 : 1561 – 1575.

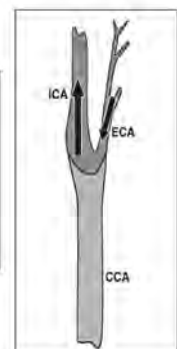
Internalization of ECA



Patient with complete occlusion of left ICA

Occlusion of CCA

Reversed flow from ECA
to supply ICA & brain
“ECA-to-ICA collateralization”

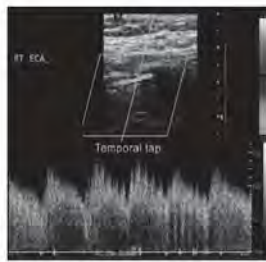


Robbin ML et al. Ultrasound Clin 2006 ; 1 : 111 – 131.

Occlusion of CCA



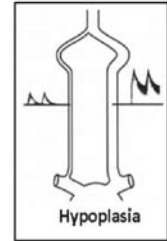
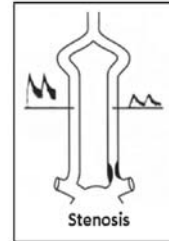
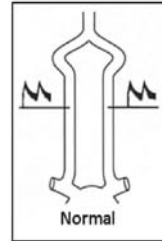
Absence of flow in distal CCA
Reversed flow in ECA
Normal flow in ICA



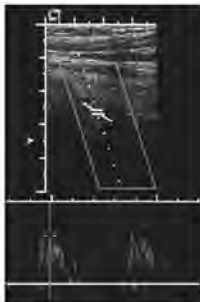
Internalization of ECA
Delayed systolic acceleration (tardus)
Positive temporal tap maneuver

Tahmasebpour HR et al. RadioGraphics 2005 ; 25 : 1561 – 1575.

Schematic Doppler waveforms of VA



High-resistance flow in vertebral artery



High-resistance flow
No diastolic component

Differential diagnosis:

Distal VA stenosis or occlusion
Hypoplastic vertebral artery

Correlation with symptoms

Dizziness
Unsteady walking

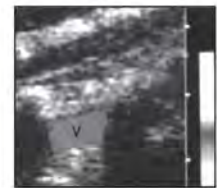
Vertebral artery occlusion

V2

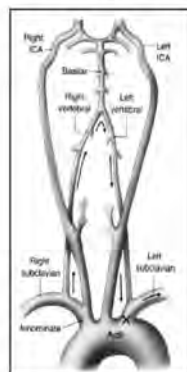
Black & white US



Color Doppler



Route of flow in left vertebral steal



Types of subclavian steal

Pre-steal or bunny waveform

Transient reversal of vertebral flow during systole
Converted to partial or complete by provocative

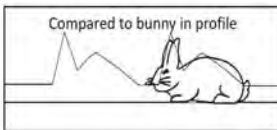
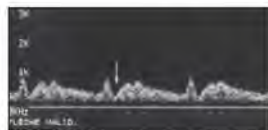
Incomplete steal

Striking deceleration of velocity in mid or late systole
High-grade stenosis of subclavian rather than occlusion

Complete steal

Complete reversal of flow within vertebral artery

Vertebral-to-subclavian steal



Incomplete steal



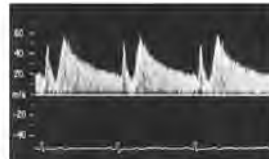
Complete steal

Rohren EM et al. Am J Roentgenol 2003 ; 181 : 1695 – 1704.

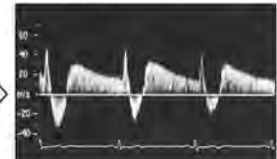
Provocative maneuver in steal syndrome

Inflation of pressure cuff on arm for 3 min & rapid deflation*

Pre-steal



More pronounced steal



Conversion of pre-steal waveform to more pronounced steal following deflation of pressure cuff

Limitations of carotid US examination

- Short muscular neck
- High carotid bifurcation
- Tortuous vessels
- Calcified shadowing plaques
- Surgical sutures, postoperative hematoma, central line
- Inability to lie flat in respiratory or cardiac disease
- Inability to rotate head in patients with arthritis
- Uncooperative patient

Tahmasebpour HR et al. RadioGraphics 2005 ; 25 : 1561 – 1575.

Advantages of power mode Doppler

- Angle independent
- No aliasing
- Increases accuracy of grading stenosis
- Distinguish pre-occlusive from occlusive lesions
“detect low-velocity blood flow”
- Superior depiction of plaque surface morphology

Disadvantages of power mode Doppler

- Does not provide **direction of flow**
New machines provide direction of flow in power mode
- Does not provide **velocity flow information**
- **Very motion sensitive** (poor temporal resolution)

Causes of carotid artery diseases

Arteriosclerotic disease

Most common cause

Non-arteriosclerotic diseases

Fibromuscular dysplasia

Dissection

Vasospasm

Aneurysm & pseudoaneurysm

Arterio-venous fistula

Arteritis: Takayasu – Horton

Carotid body tumor

Idiopathic carotidynia

Causes of carotid artery diseases

Arteriosclerotic disease

Most common cause

Non-arteriosclerotic diseases

Fibromuscular dysplasia

Dissection

Vasospasm

Aneurysm & pseudoaneurysm

Arterio-venous fistula

Arteritis; Takayasu – Horton

Carotid body tumor

Idiopathic carotidynia

Doppler US of carotid arteries

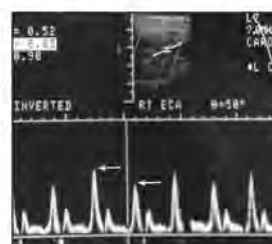
- ① Anatomy of carotid arteries
- ② Normal Doppler US of carotid arteries
- ③ Causes of carotid artery disease
- ④ Effect of extra-carotid diseases

Effect of extra-carotid diseases

- Idiopathic dilated cardiomyopathy
- Aortic regurgitation
- Aortic stenosis
- Stenosis of right innominate artery or origin of LCCA
- High & low PSV in CCA
- Stenosis of intra-cranial ICA

Idiopathic dilated cardiomyopathy

Pulsus alternans

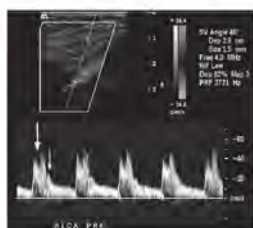
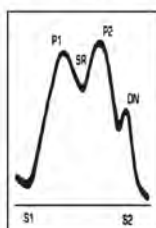


PSV oscillating between two levels on sequential beats
Cardiac rhythm remains regular throughout

Rohren EM et al. Am J Roentgenol 2003 ; 181 : 1695 – 1704.

Aortic regurgitation

Bisferious waveform [“beat twice” in Latin]



Two systolic peaks separated by midsystolic retraction
Dicrotic notch
Found also with hypertrophic obstructive cardiomyopathy

Kallman CE et al. Am J Roentgenol 1991 ; 157 : 403 – 407.

Rohren EM et al. AJR 2003 ; 181 : 169 5– 1704.

Severe aortic regurgitation

Water-hammer spectral appearance

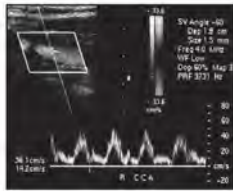


Normal or elevated PSV followed by precipitous decline
Reversed flow during diastole

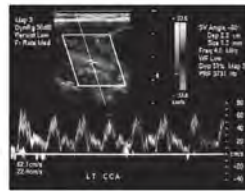
Rohren EM et al. Am J Roentgenol 2003 ; 181 : 1695 – 1704.

Aortic stenosis

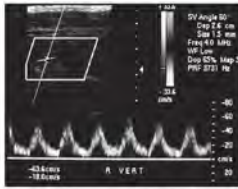
RCCA – Tardus-Parvus



LCCA – Tardus-Parvus



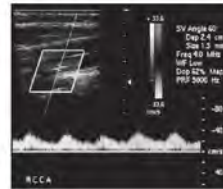
RVA – Tardus-Parvus



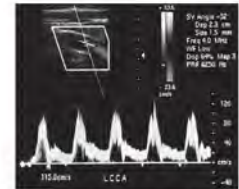
Scoutta LM et al. Ultrasound Clin 2006 ; 1 : 133 – 159.

Right innominate artery stenosis

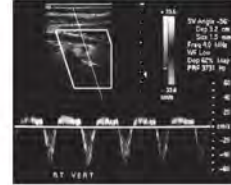
RCCA – Tardus-Parvus



LCCA – Normal waveform

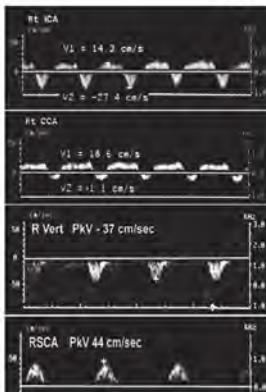


RVA – Reversed flow



Right innominate artery stenosis

Right carotid steal



RICA : to-and-fro flow

RCCA : to-and-fro flow

RVA : reversed flow

RSCA : damped flow

Normal PSV in CCA (45 – 125 cm/sec)

High flow > 125 cm/sec in both CCAs

High cardiac output: Hypertensive patients
Young athletes

Low flow < 45 cm/sec in both CCAs

Poor cardiac output: Cardiomyopathies
Valvular heart disease
Extensive myocardial

Arrhythmias can be real problem

Stenosis of intra-cranial ICA

High resistance waveform



High-grade stenosis distally (intracranial ICA)

Major occlusive lesions of cerebral arteries (MCA, ACA)

Massive spasm of cerebral arteries from intracranial hemorrhage